Modeling and Observations of Surface Waves in Monterey Bay

Le Ngoc Ly
Department of Oceanography, Code OC/Le
Naval Postgraduate School
Monterey, CA 93943
phone: (831) 656-3257; fax: (831) 656-2712; email: lely@oc.nps.navy.mil

Jeffrey D. Paduan
Department of Oceanography, Code OC/Pd
Naval Postgraduate School
Monterey, CA 93943
phone: (831) 656-3350; fax: (831) 656-2712; email: paduan@oc.nps.navy.mil

Document #: N00014-00-WR20098
http://www.oc.nps.navy.mil/~icon/

LONG-TERM GOALS

The long-range goals of this project are to develop an improved turbulence closure model that takes explicit account of surface wave effects and to quantify the effect of Stokes drift on the surface current signature of High Frequency (HF) radar systems.

OBJECTIVES

The objectives of this project are to: 1) deploy a surface buoy with turbulent flux and surface wave measurement capabilities within the footprint of the HF radar network in Monterey Bay and 2) formulate a new turbulence closure scheme based on surface wave dynamics that can be evaluated using data from the flux buoy.

APPROACH

This project is extending the measurement and modeling efforts already underway in the Monterey Bay region to include the direct measurement and modeling of surface waves. It is combining three efforts to assemble a better surface flux parameterization: 1) the Ly et al. wave modeling, 2) the Davidson et al. meteorological flux observations, and 3) the NOPP/ICON coastal modeling.

WORK COMPLETED

Three separate deployment of the NPS Flux Buoy have taken place for 30-60 day periods: Fall 1999, Winter 2000, and Fall 2000 (co-sponsored by an ICON follow-on). The formulation of a new turbulence closure scheme based on surface wave dynamics has been completed and the initial implementation of the scheme has been attempted within the POM-based models of Ly (NAval

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Modeling and Observations of Surface Waves in Monterey Bay**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Oceanography, Code OC/Le,,Naval Postgraduate School,,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

postgraduate school ocean Model; NAM) and Shulman (Innovative Coastal-Ocean Observing Network model; ICON).

RESULTS

The instrumented NPS FLUX buoy was assembled, checked out and deployed in Monterey Bay to provide in situ measurements of surface waves and atmospheric forcing by K. Davidson of the NPS Meteorology Department (see: http://www.met.nps.navy.mil/~jonesk/BuoyHistory/ppframe.htm). In addition to bulk wind and temperature observations, critical turbulent flux data on wind stress and directional surface wave spectra were collected at the mooring site within Monterey Bay. Of particular interest here is the directional wave spectra, which are being used in the model to test the wave age parameterizations. These continuous, 2-D wave data are also being used to assess the impact of Stokes currents on high frequency (HF) radar backscatter measurements. A sample wave spectrum from the Fall 1999 deployment is shown in Figure 1.

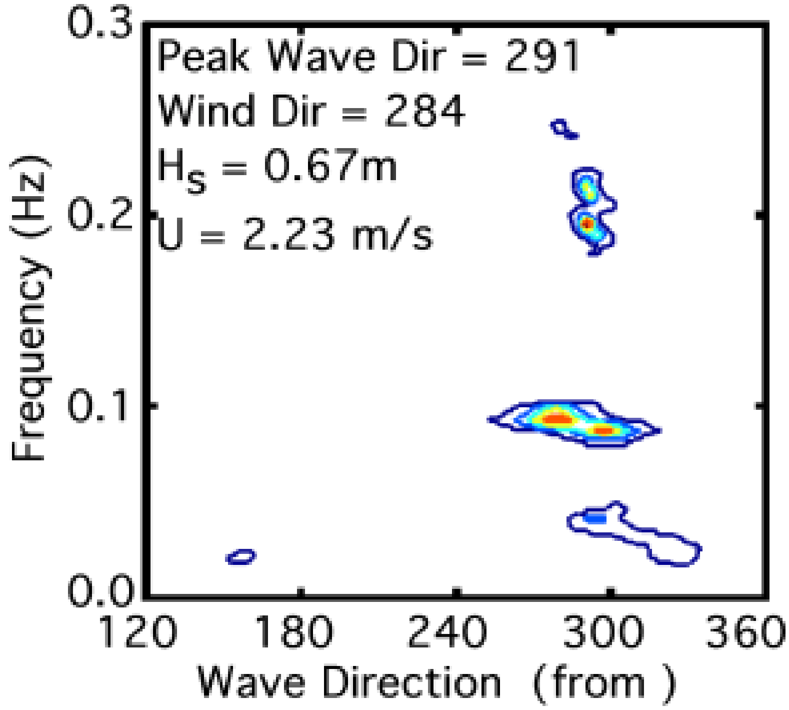

Figure 1. Directional wave spectrum for 1400 UTC on 5 October 1999.

A new turbulence closure with surface wave parameterization (Ly, 1995; Ly and Garwood, 2000; Ly et al. 2000a) was developed for the oceanic and atmospheric models taking surface ocean waves into account. This turbulence closure has been developed based on a new concept of turbulent energy sources related to both shear production (classical theory) and breaking waves using the semi-empirical turbulence and similarity theories, and a linear theory of breaking waves. The turbulence scheme with a new wave parameterization has been tested using the NPS 1-D air-wave-sea interaction coupled model and new data of dissipation distribution in the ocean, and other air-sea interaction characteristics, such as wave-dependent drag coefficient, roughness length, and momentum fluxes. The numerical studies and data-model comparisons show that the new theory can predict (better than the classical theory) wave-dependent turbulent kinetic energy dissipation (Figure 2) in the ocean (and it is expected in the marine atmospheric turbulent layer). The wave-dependent drag coefficient (Figure 3) and wave-dependent roughness length also agrees well with the observed data (Ly and Garwood, 2000). The most important point is that a close comparison of the new theory with all available data was made and the first full application of the model results to ocean circulation models, such as the Princeton Ocean Model (POM) and NAM (Ly et al., 2000a), was conducted, beginning the move toward a true coupled circulation-wave system.

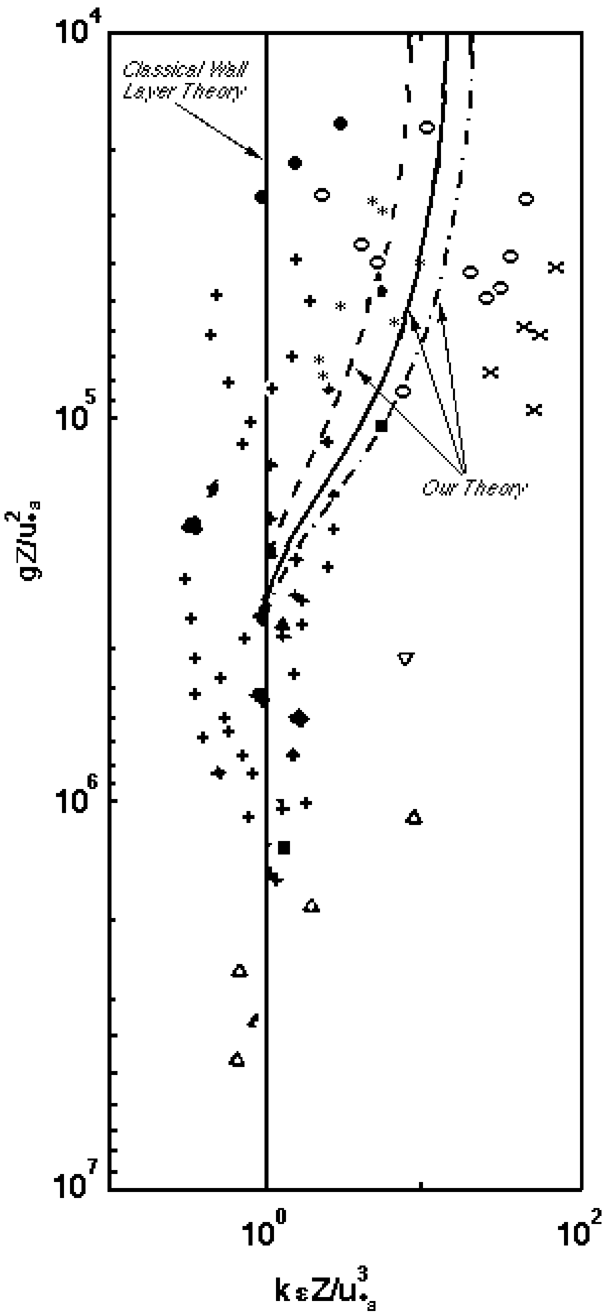

Figure 2. Various measurements (symbols) of nondimensional dissipation, epsilon, as a function of nondimensional depth. Data points adapted from Agrawal et al. (1992) along with the classic wall-layer theory distribution and a range of results from the new wave parameterization.

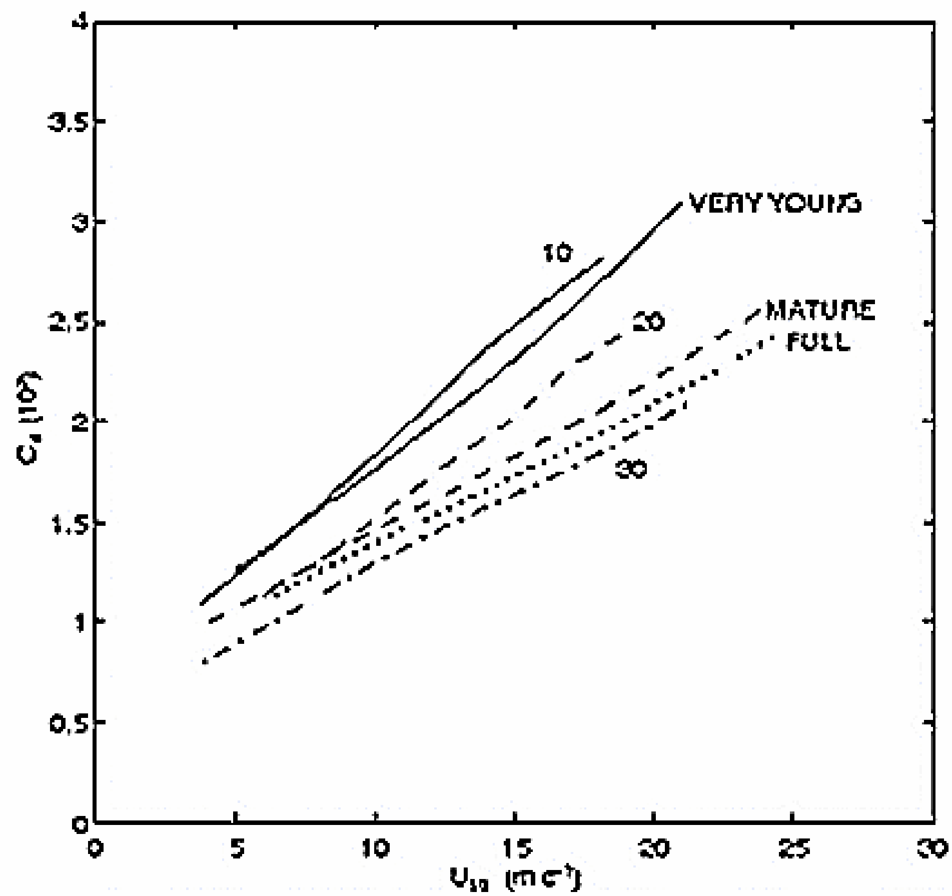

Figure 3. Dependence of model drag coefficients on 10-m height winds and wave ages equal to 10, 20, and 30. Three other curves with "very young", "mature", and "full" from observational data by Smith et al. (1992).

The new turbulence closure with a full wave parameterization has been used to develop the NAM ocean circulation model with multi-block grid features, which allow better handling of complicated bottom topography, coastlines and multi-scale physical phenomena in modeling domains. Multi-block grid techniques also have superior properties in parallel computing in comparison with the traditional single block grid and domain-decomposition techniques (Luong et al., 2000abc). The model has also been used to develope a barotropic tidal model for the Monterey Bay region. These results have been written up as an invited paper for the International Hydraulic Engineering Software VIII Conference, 2000 (Ly, et al., 2000b).

As part of this project, a modification of the new surface wave parameterization for idealized wave height and wave age fields has been also incorporated within the ICON modeling and data assimilation effort. Our first version of a new PROFQ subroutine, along with some modifications to the MAIN program, have been transferred to Igor Shulman and James Lewis of that project. Also, a new version of subroutine PROFU with an equation of energy fluxes for taking drift current-wave relationship is being transferred to the ICON modeling group for testing. It is noted that the wave parameterization was partly modified for use in POM and other models utilizing mixing length theory. In this way, POM can take the wave-turbulence relationship (without turbulence dissipation) into account. (At this time, only the NPS NAM version can take a full wave-turbulence relationship into account.)

The NAM box model was used in a circulation-wave coupling study with idealized wave height and wave age fields (Ly, et al., 2000a). This study focused on the sensitivity of the current field to the surface waves. It also demonstrates the capability of NAM in reproducing an upwelling feature for the idealized California coastal region. Simulation showed that surface currents are strongly sensitive to surface waves in a complex wind-wave-turbulence-current relationship. Simulations also show that ocean models that do not take surface waves into account can overestimate currents up to 50 %.

IMPACT/APPLICATIONS

The likely impacts of this research will include improved understanding of the effects of surface waves on the measurement of surface currents by HF radar installations along with an expanded capability to include the effects of surface waves within turbulence closure schemes used by primitive equation models. The application of these results should lead to fundamentally improved models and more accurate remotely sensed surface currents.

TRANSITIONS

The transition opportunities are related to next-generation ocean circulation models and coupled atmosphere-wave-ocean models. These models will require improved parameterizations of the effects of surface waves on turbulent transport near the ocean surface. In addition, the information about the effects of surface waves on HF radar measurements will be needed to correct observed surface current fields prior to assimilation into ocean circulation models.

RELATED PROJECTS

This project represents and extension of the efforts underway as part of the Monterey Bay component of the National Ocean Partnership Program (NOPP/ICON). It also complements the ICON coordination with the field tests of the ONR-sponsored Autonomous Ocean Sampling Network (AOSN) conducted in Monterey Bay in August 2000. Information about this project and the broader ICON and AOSN efforts can be found at: http://www.oc.nps.navy.mil/~icon .

REFERENCES

Agrawal Y. C., E. A. Terray, M. A. Donelan, P. A. Hwang, A. J. Williams, W. Drennan, K. K. Kahma, and S. A. Kitaigorodskii, 1992: Enhanced dissipation of kinetic energy beneath breaking waves. Nature, **359**, 219-220.

Benilov, A.Yu. and L.N. Ly, 2000: Modeling of Surface Waves Breaking Effects in The Ocean Upper Layer. Mathematical & Computer Modelling. (In press).

Ly, L. N., 2000: www.oc.nps.navy.mil/~lely.

Ly, L. N. and R. W. Garwood, Jr., 2000: Numerical Modeling of Wave-Enhanced Turbulence in the Oceanic Upper Layer. J. Oceanography. **56**, 473-483.

Ly, L. N., R. W. Garwood, Jr., J. D. Paduan, Yu. A. Benilov, and P. Luong, 2000a: On Circulation-Wave Coupling With a Surface Wave Parameterization. AGU EOS Fall Meeting. (In press).

Ly, L. N., W. P. O'Connor, and J. D. Paduan, 2000b: A Barotropic Simulation of Semi-Diurnal and Diurnal Tides for the Monterey Bay Region. Coastal Dynamics and Estuaries, in Hydraulic Engineering Software VIII, W. R. Blain and C. A. Brebbia (ed.), Computational Mechanics Publications, 155-169.

Ly, L. N., 1995: A Numerical Coupled Model for Studying Air-Sea-Wave Interaction. Physics of Fluids. **7** (10), 2396-2406.

Luong, P., C. P. Breshears, and L. N. Ly, 2000a: Application of Multi-Block Grid and Dual-Level Parallelism in Coastal Ocean Circulation Modeling. SIAM J. on Scientific Computing. (Submitted).

Luong, P., C. P. Breshears, and L. N. Ly, 2000b: Dual-Level Parallelism and Multi-Block Grids. Thirteen International Conference on Parallel and Distributed Computing Systems. Proceedings, 361-66.

Luong, P., C. P. Breshears, and L. N. Ly, 2000c: Dual-Level Parallelism Improves Load-Balance in Coastal Ocean Circulation Modeling. ERDC MSRC PET Technical Report, Vicksburg, MS, 23 pp.

Smith, S. D., R. J. Anderson, W. A. Oost, C. Kraan, N. Maat, J. DeCosmo, K. B. Katsaros, K. L. Davidson, K. Bumke, L. Hasse, and H. M. Chadwich, 1992: Sea Surface Wind Stress and Drag Coefficients: The HEXOS Results. Boundary-Layer Meteorol., **60**, 109-142.

PUBLICATIONS

Benilov, Yu. A. and L. N. Ly, 2000: Modeling of Surface Waves Breaking Effects in the Ocean Upper Layer. Math. and Computer Modeling.

Ly, L. N. and R. W. Garwood, Jr., 2000a: An Ocean Circulation Model With Surface Wave Parameterization Using Pivotal-Condensation Method. Applied and Computational Mathematics. (Submitted).

Ly, L. N. and R. W. Garwood, Jr., 2000b: Numerical Modeling of Wave-Enhanced Turbulence in the Oceanic Upper Layer, J. Oceanography, **56**, 473-483.

Ly, L. N., W. P. O'Connor, and J. D. Paduan, 2000: A Barotropic Simulation of Semi-Diurnal and Diurnal Tides for the Monterey Bay Region. Coastal Dynamics and Estuaries, in Hydraulic

Engineering Software VIII, W. R. Blain and C. A. Brebbia (ed.), Computational Mechanics Publications, 155-169.

Luong, P., C. P. Breshears, and L. N. Ly, 2000: Application of Multi-Block Grid and Dual-Level Parallelism in Coastal Ocean Circulation Modeling. SIAM J. on Scientific Computing. (Submitted).

Luong, P., C. P. Breshears, and L. N. Ly, 2000: Dual-Level Parallelism and Multi-Block Grids. Thirteen International Conference on Parallel and Distributed Computing Systems. Proceedings, 361-66.

Luong, P., C. P. Breshears, and L. N. Ly, 2000: Dual-Level Parallelism Improves Load-Balance in Coastal Ocean Circulation Modeling. ERDC MSRC PET Technical Report, Vicksburg, MS, 23 pp.

Ly, L. N., P. Luong, J. D. Paduan, and D. Koracin, 1999: Response of the Monterey Bay Region to Wind Forcing by an Atmospheric Model. Third Conference on Coastal Atmospheric and Oceanic Prediction and Processes. Proceedings, 76-79.

Miller, A. J, J. C. McWilliams, N. Schneider, L. N. Ly, et al., 1999: Observing and Modeling the California Current System: Purpose, Achievements and Aspirations. EOS Trans. AGU. Vol80, 45, 533.

Ly, L. N. and P. Luong, 1999: Numerical Multi-Block Grids in Coastal Ocean Modeling. Applied Mathematical Modelling, Vol. **23**, 11, 865-879.

Ly, L. N. and R. W. Garwood, Jr., 1999: On Breaking Wave-Enhanced Turbulence in the Oceanic Surface Boundary Layer. AMS Thirteen International Symposium on Boundary Layers and Turbulence. Proceedings, 359-361.

Ly, L. N. and L. Jiang, 1999: Horizontal Pressure Gradient Errors of the Monterey Bay Sigma Coordinate Ocean Model with Various Grids. J. Oceanography, **55**, 87-97.

Ly, L.N. and P. Luong, 1999: Numerical Grids Used in a Coastal Ocean Model with Breaking Wave Effects. Computational and Applied Mathematics, **103**, 125-137.